FM Radio Propagation and AREPS Model Verification

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Introduction and Purpose

UHF radio propagation has not been studied by any OC3570 class cruise. Nor has the accuracy of the newest AREPS communications module. The focus of this project is to combine these two objectives and study/verify the accuracy of the AREPS communications module using FM radio intercepts off the coast of California and rawinsondes taken on the cruise for temperature and humidity profiles. This will provide valuable feedback to the project team developing AREPS and expanded the meteorological aspects of the cruise.

Theoretical review

FM radio broadcasts in the frequency band of 87.9 to 107.9, which is in the UHF band. These frequencies propagate primarily in a line of mode, but can be refracted or ducted based on the profile of temperature and humidity with height. Figures 1-3 detail ducting types. These profiles are based on the modified refractivity index (M), which is the index of refraction based on the curvature of the earth. Figure 1 shows the M profile for an elevated duct, a surface duct and an evaporation duct. Figure 2 and figure 3 show shadow zones for a transmitter above the duct. These shadow zones appear in some of the model runs described below.

There is a specific relationship between the thickness of the duct and the UHF frequencies that can be trapped in the duct. Equation 1 describes this relationship and equations 2-5 show the thickness calculation for the frequencies of interest. The receiver was calibrated at a frequency of 98.1 Mhz. Figure 3 is a plot of the frequency versus duct thickness for trapped and not-trapped frequencies. Based on these calculations, FM frequencies are trapped by a duct thickness between 256 and 223 meters. It is expected that if a radio station transmitted from over the geometric horizon it will only be received if there is a duct to aid in propagation.

Measurements

For data collection, an ICOM IC-R series receiver was used. This HF and UHF capable receiver was set up using the high gain mast mounted antennae on the RV Point Sur. It was digitally tuned to FM wide band signals and the frequency, signal strength and program type of call sign recorded approximately once every hour during the first two segments of the cruise. This was from 5 to 11 August 2004. When ocean conductivity, temperature and depth (CTD) casts were in progress, FM data was not taken. The data was taken initially at the bottom of the hour, but about one day into the second cruise segment they started being taken at the top of the hour. This was because the Federal Communications Commission (FCC) requires all stations to use their registered call sign within five minutes

$$f_{\min} = \left(\frac{3.6 \times 10^{11} Hz}{m^{-3/2}} \right) d^{-3/2}$$

Equation 1. Minimum frequency that will be trapped by a surface duct based on a given thickness (Davidson, 3-32).

$$d_{\min} = \left(\frac{3.6 \times 10^{11} Hz \times m^{-3/2}}{f_{\min}} \right)^{-3/2}$$

Equation 2. Duct thickness that will trap a signal with a given frequency.

$$d_{\min} = \left(\frac{3.6 \times 10^{11} Hz \times m^{-3/2}}{87.9 \times 10^{6} Hz} \right)^{2/3} = 256.0m$$

Equation 3. Duct thickness that will trap a signal with a frequency of 87.9 Mhz.

$$d_{\min} = \left(\frac{3.6 \times 10^{11} Hz \times m^{-3/2}}{107.9 \times 10^{6} Hz} \right)^{2/3} = 223.3m$$

Equation 4. Duct thickness that will trap a signal with a frequency of 107.9 Mhz.

$$d_{\min} = \left(\frac{3.6 \times 10^{11} Hz \times m^{-3/2}}{98.1 \times 10^{6} Hz} \right)^{2/3} = 237.9m$$

Equation 5. Duct thickness that will trap a signal with a frequency of 98.1 Mhz.

of the top of the hour. On the initial track out form Monterey, only the 12 strongest signals as measured in port in Moss Landing were recorded. This made the data on this leg less useful due to a lack of complete data.

There were some problems with the recording of the signal strength. The receiver meter was scaled on the left with a linear reading of 0 to 9 and on the right with a logarithmic scaled dB reading “9 plus” up to +60 dB. This corresponded to a classic radio operator reporting procedure (James). There was some confusion about how to record these readings and some interpolation was required during data entry from the logs. There was also a signal centering function that used the same meter as the signal strength and was toggled by a switch. Several hourly data sets showed constant signal strength for all stations, which indicated that the switch had been toggled to center, vice signal strength and this data had to be thrown out.

Recording the program type or call sign was a great help in correlating intercepts with radio station transmitters. Without this data, it would have been impossible to determine which transmitter was being received.

The ICOM IC-R series receiver was calibrated with a test signal generator at 80 ohms. This method was chosen because the equipment required to radiate a known test signal into the antennae on the RV Point Sur was not available. The calibration data is in Table 1 and was taken near the center of the FM frequency band at 98.1 MHz. The value of gain at signal strength “9” was –84 dBm. This was the value used in AREPS for the receiver gain.

Signal Strength reading on ICOM	**Gain Measured On test source**
SS 7	-92 dBm
SS 9	-84 dBm
+20 dB	-64 dBm

+30 dB	-51 dBm

Table 1. ICOM Receiver Calibration Data

Atmospheric data was collected using Visalia RS-80 rawinsondes. The soundings measured pressure, temperature and relative humidity. The published accuracy and resolution of these instruments is listed in Table 2. There were some noted problems with these rawinsondes. Even in clouds they did not indicate saturation conditions and a humidity bias was assumed. The estimated accuracy of the sondes used was ±5°C for temperature and ±5% for relative humidity (Guest).

Accuracy	
Temperature	0.2 °C
Relative Humidity	2.0 %
Pressure (Height)	0.5 hPa (5 m)
Resolution	
Temperature	0.1 °C
Relative Humidity	1.0 %
Pressure (Height)	0.1 hPa (1 m)

Table 2. Published rawinsonde calibration (Visalia Corporation)

Figure 4 shows the location of all the collection points for FM receiver data and Figure 5 shows rawinsonde data collection points. Figure 4 also shows the FM stations in California with a transmit power over 1 Kw and symbols proportional in size to the transmit power.

Data Analysis

Raw FM radio station data was entered into a Microsoft Excel spreadsheet by hand. A delimited text file with all the registered FM stations in California was downloaded from a FCC website and converted to another Excel spreadsheet (FCC). Both were exported as Dbase IV files and imported into the ERSI ARC Map program. They were then displayed by geographic position. There were several errant locations for FM data that were due to data entry errors based on being 1° off on latitude or longitude.

These records were corrected in ARC Map. The FM data was then graphically sorted by frequency and correlated to Transmitter data sorted similarly. This was where the ARC Map program really helped to correlate data. Having to look at all the receiver data and transmitter data by hand would have taken much longer than the time spent entering the receiver data. Although the program type was not entered into the Excel spreadsheet, careful review of the handwritten logs was a great check to verify the proper transmitter for a given reception.

The central track in and out from Port San Louis became the focus of Advanced Refractive Index Prediction System (AREPS) runs because there were two sets of both rawinsonde and radio intercepts one day apart with a varying sounding profiles and mostly complete FM station logs. Five frequencies were chosen for analysis based on when and where they were received and the ability to correlate the signals by program type to a specific transmitter. The five frequencies and stations were: KUSC Los Angeles 91.5 MHz, KDB Santa Barbara 93.7 MHz, KBAA Gilroy 94.5 MHz, KPYG Cambria 94.9 MHz and KJFX Fresno 95.7 MHz.

The rawinsonde data was imported into the AREPS program using the “Create new Environment” environment module. Because the balloons for the rawinsondes had been intentionally launched with leaks in them, there was both an “upcast” and “downcast”. AREPS has a “rocketsonde” feature that allows for the data to be arranged by ascending height. This combined the up and down casts into a single sounding. Although this feature was used, in the future it may prove more accurate to use a separate data smoothing routine to get a single clean sounding as was done for the CTD data collected on the cruise. The AREPS program could also be updated to carry out similar data smoothing.

Figure 6 shows the progression of soundings from seaward to land on 7 August and then landward to sea on 8 August. These soundings appear in subsequent figures of the AREPS receive predictions. The progression of soundings was 12-15 inbound and 16-19 outbound.

AREPS Data and Correlation

The first discussion required about the AREPS data run must be about the difficulties encountered using the 3.3 Beta version of the AREPS program. Several bugs were noted, the most annoying of which was the fact that the longitude fields did not recognize a minus sign as west longitude. Even after manually changing the longitude to west by placing a “w” in the field, after the program had converted degrees and decimals to degrees minutes and seconds, the geographic position did not update properly in other modules. This may have been because the data was not entered and saved in the right sequence but was clearly not “sailor proofed”. Because this bug was not detected until late in the data analysis process, all the figures produced are in the wrong hemisphere. This primarily affected orographic shading, which was absent in all but one case and inaccurately displayed in that case. The majority of figures were essentially run over water with one over a northeast Asia land mass. The functionality and correlation of actual receive data and the AREPS predictions was still good in all but one case and provided valuable data into the basic function of the program and had one case with topography that did correlate.

The major problem with the setup of this AREPS experiment is that AREPS is running a range independent model based on the sounding at a single at sea location. The actual sounding is expected to change with range as seen in the progression of soundings in figure 6. The over land sounding is also expected to be markedly different than the sounding at sea. For this reason alone the model runs are suspect, but the analysis still represents a good starting point for verification.

The AREPS propagation display used was the default, which shows orange for no detection and red for detection based on a signal strength calculated from the sounding. Although there may be other displays and color schemes possible, the beta version of the program did not appear to use them. When viewing these graphs, the assumed receiver antennae height is 15 meters. AREPS generally showed one of three characteristics: solid detection, solid no detection or marginal detection at long range. The first represents a duct and the third line of sight propagation. Several of the third type showed periodic gains indicative of shadow zones.

Frequency Data and Model Comparison

The first frequency, 91.5 FM from KUSC in Los Angeles, was received only near the coast, but not at the closest stations. Locations and the AREPS receive predictions are in figure 7. They agree with the at sea data. Station 12 and 19 show no detection with solid detection at stations 14 and 15 and marginal detection at station 17. As mentioned above, topographic shadowing was not a factor in the predictions.

93.7 FM from KDB in Santa Barbara was received at the outer stations and not the inner ones as seen on figure 8. AREPS correctly predicted no signal at stations 15 and 17 and detections at stations 12, 18 and 19. A strong Fresno station was also broadcasting at this frequency, but the KDB, top 40, correlated with detections and the Fresno was a country station.

94.5 FM from KBAA in Gilroy was the only case with topography. AREPS correctly predicted reception only in the middle of the track on the inbound leg. As seen on figure 9, stations 12 and 19 showed a solid no detection and station 14 had a solid detection. Although not shown in the figure, station 17 showed no detection on the outbound leg. This was the only case of temporal variation noted in the five cases studied. The profile for station 17 shows a surface based duct at ~400 feet and this may account for the shadow on 8 September if the transmitter was above the layer as modeled by the topography. Once again the program type was useful in correlating the detection near station 14 because it was a Spanish station and all the other stations broadcasting on 94.5 were not.

94.9 FM from KPYG in Cambria, on the coast just north of Port San Louis, is shown in figure 10. This was the only case where AREPS predicted a detection that was not recorded in the actual data. The AREPS predictions show solid detections all the way to the coast with the best reception close to the transmitter at station 17. Actual data showed detections only near the outer stations. The reason for this anomaly is not readily apparent from the soundings and requires more investigation. The hardcopy receive data was verified to see that there was no data entry error.

95.7 FM from KSFX in Fresno was the most surprising detection. Figure 11 shows the detection locations and AREPS predictions. The records showed a rock and rap station. There was a small 1 Kw transmitter in the Santa Barbara range, but it was a Baptist church and did not correlate with the hard-core rap recorded. There were several strong transmitters in the San Diego area that were on the same frequency but they were both country. This left the Fresno station that, according to their website, played 80s music including rap. The data showed detection near station 12 and 14 inbound and not at 15 and 18 outbound. AREPS predicted detection at 14 and no detection at 15 and 18 with some banding but mostly no detection at 12. Here we saw detection where AREPS did not predict it.

Conclusions

With four out of five cases showing good correlation between recorded detections and AREPS predictions, the model performed well within the limitations discussed earlier. The four well-correlated cases displayed both geographic and temporal variation in the environment and the AREPS model showed good correlation with both variations. In the Cambria station case, KPYG, the AREPS model predictions were intuitively correct since the transmitter was the closest of any case. There may have been an error in logging this station.

The development and use of a range dependent UHF propagation tactical decision aid would certainly improve predictions. The rather crude UHF communications module in the AREPS program is not capable of doing this kind of long range and cross-coast prediction. There were many bugs in the 3.3 Beta version of the software, including many data entry and graphical used interface problems that will be sent to the program manager as feedback.

Recommendations

There was enough data collected to prepare a thesis. But the limitations in data entry in the AREPS program and the inability to import transmitter and receiver data would make the process of running the thousands of correlated data points untenable. If an automated routine could be developed, this could provide a valuable set of data for more thorough model verification. As mentioned above, the use of a data-smoothing algorithm on the rawinsonde data would have provided a cleaner sounding from the multiple casts.

Several procedural problems inhibited the data taking process. With hindsight, getting and testing the receiver well before the cruise and having a firm understanding of the way the instruments read would have greatly aided the process. This would have allowed a training session on the classroom on how to tune and record the data properly I am indebted to Sim James for explaining the signal strenth method used on the ICOM reciever. Also, as was recomended to me, calibrating the reciever prior to the cruise would hava allowed the signal strenght data to be entered as dBm gain and prevented the tedious conversion after the data was already in a spreadsheet.

References

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